National Aeronautics and Space Administration

2016 HEALTH & AIR QUALITY

NASA Earth Science
Applied Sciences Program

Health & Air Quality: 2016 Annual Summary

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I. Introduction

The ESD Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science research and applications projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products into practitioners' decision making, and transfer the applications. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and benefits from the Earth observations.

The Applied Sciences Program's applications themes are currently focused on four of the nine Societal Benefit Areas (SBAs) of the interagency U.S. Group on Earth Observations (USGEO): Health (including Air Quality), Disasters, Ecological Forecasting, and Water Resources.[1] The Program includes climate-related influences and impacts within each of these themes.

The Health & Air Quality Applications area encourages the use of Earth observations in air quality management and public health, particularly involving environmental health and infectious diseases. The area also addresses the effects of climate change on air quality and public health to support managers and, ultimately, decision-makers of health-related issues.

II. Overview of 2016

The past year was a productive one for the Health & Air Quality Applications area, with projects concluding or achieving significant milestones. Projects addressed public health issues such as air quality, infectious diseases, vector-borne diseases, environmental health, and harmful algal blooms (HABs). Thirteen new investigators were selected for funding through the ROSES 2015 Health and Air Quality Applied Sciences Team (HAQAST) solicitation. Current projects in the portfolio met or exceeded expectations regarding technical performance. In addition, projects received media coverage or substantial praise from stakeholders on the value of the respective applied science.

The Health & Air Quality program continued to support online resources to disseminate important information and data covering health surveillance, the effects of global climate change on public health, and air quality management. In 2016, the program launched a new monthly Health and Air Quality newsletter that is circulated online and via a mail list. The applications area distributed applied research results and led or participated in meetings across the air quality Earth science community, at both the national and international levels.

[1] The nine USGEO SBAs are Agriculture, Climate, Disasters, Ecological Forecasting, Energy, Health, Oceans, Water Resources, and Weather.

The following report summarizes a few challenges and many achievements that occurred during 2016. The Health & Air Quality Applications area looks eagerly toward the coming years, including future solicitations, continued support for airborne field campaigns, as well as the support of, and applications planning for, relevant satellite missions.

III. Major Accomplishments

Some of the notable programmatic achievements this past year include:

In Summer 2016, the US Environmental Protection Agency (EPA) used OMI NO_2 satellite data in its *Air Trends Report* (https://gispub.epa.gov/air/trendsreport/2016). This marked the first time that the report utilized satellite data. The data cover nearly one decade of NO_2 annual concentrations in the United States, and confirm a steady decline in this criteria air pollutant controlled under the Clean Air Act. Due to this decline, the report states, "today Americans breathe cleaner air and face lower risks of premature death and other serious health effects." Similar images for individual cities in the US and globally are also available. According to the EPA, annual concentrations of Nitrogen Dioxide (NO_2) have decreased by 54 percent since 1990, while the U.S. economy has continued to grow alongside increases in population, number of car miles driven, and energy consumption.

One of the key tools used by decision makers across the U.S. to protect the public from adverse health effects caused by poor air quality is the National Oceanic and Atmospheric Administration (NOAA)/National Centers for Environmental Prediction (NCEP) operational air quality forecasting system; the National Air Quality Forecasting Capability (NAQFC). To enhance this decision-making activity, the program awarded a project in 2014 to improve the accuracy of NOAA/NCEP short-term predictions of ground-level ozone and particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and to provide reliable quantification of their uncertainty by exploiting NASA Earth science data with chemical data assimilation and analog-based approaches. In 2016, the project achieved the major milestone of running the 2D gridded deterministic procedure operationally on NOAA/NCEP computing platforms.

Cholera, an acute and highly infectious diarrheal illness, remains a major threat to global health, especially in developing countries of sub-Saharan Africa and South Asia. To address this critical problem, a multi-disciplinary team of U.S.-based scientists from West Virginia University, the University of Rhode Island, the University of Maryland, and Moravian College has partnered with the International Centre for Diarrhoeal Disease Research in Bangladesh on a ground-breaking initiative to combine satellite remote sensing data and ground observations to assess and predict risk of cholera outbreaks in Bangladesh. In 2016, this team focused on monitoring regional hydroclimatic processes and

changes in the natural aquatic ecosystems using observations from several NASA satellites (e.g., TRMM archival data, MODIS) to develop a model of cholera outbreak risk. The team also used this data to map unsafe water sources in times of water scarcity and flooding.

The California Vectorborne Disease Surveillance (CalSurv) Gateway has been in operation since 1996, originally as a decision-support system for West Nile Virus. In 2014, NASA awarded a project to enhance CalSurv decision support tools for dengue, chikungunya virus, and for mosquito vector control. As Zika virus is transmitted by the same types of mosquitoes as chikungunya virus and dengue, NASA supplemented this project in 2016 to address this emerging threat. The project focuses on decision support tools for controlling the invasive *Aedes aegypti* and *Aedes albopictus* mosquitoes, and for estimating and mapping the risks for dengue, chikungunya, and Zika viruses. MODIS land surface temperatures (used for mosquito microhabitat temperatures), downscaled CMIP5 model outputs, and NDVI calculated from high resolution USDA NAIP data are all utilized in the project. NASA's NEX computing platform is used for mosquito habitat modeling.

The ROSES 2013 Health and Air Quality Applications solicitation allowed proposers to express interest in a socioeconomic impact analysis of their project. The solicitation indicated that the program would follow-up post-selection to pursue these impact assessments on a subset of the awarded projects. In 2016, two proposals were augmented for socioeconomic impact analysis. The two projects selected were: "A Multi-Sensor Remote Sensing Approach to Predict Cholera" (PI: Antar Jutla of West Virginia University) and "Chemical Data Assimilation and Analog-Based Uncertainty Quantification to Improve Decision-Making in Public Health and Air Quality" (PI: Luca Delle Monache of NCAR).

The Health and Air Quality program collaborated with Capacity Building's Applied Remote Sensing Training program (ARSET) to bring remote sensing resources to the public health community through the first-ever training sessions focused on health applications. The training entitled, "Fundamentals of Remote Sensing for Health Monitoring," occurred in June 2016 and engaged 368 attendees. The training covered topics including detection of harmful algal blooms and calculation of mosquito-borne disease risk, all using NASA Earth observations. In a post-training survey, 91 percent of respondents indicated their ability to access remote sensing data products improved as a direct result of the training. One participant appreciated "knowing that there is an open database with remote sensing [data] that could be used in practical epidemiological problems and solutions." Another attendee, a member of a U.S. State government, noted "[a]s a novice regarding remote sensing and its application for global health issues and patterns, I found the webinar series to be highly useful. The presenters taught the material in a manner [that] was easy to understand while touching on several technical aspects of remote sensing." Additionally, the program led another round of training at CDC's annual Environmental Tracking Network

meeting in October in Atlanta. More training sessions are planned for 2017.

The spotlight article of the September 2016 issue of *Lancet Respiratory Medicine*, titled "New generation of satellites will shed light on respiratory diseases," featured the Health and Air Quality program's John Haynes, who described NASA's new generation of public health-oriented satellite missions, including the Multi-Angle Imager for Aerosols (MAIA) and Tropospheric Emissions: Monitoring Pollution (TEMPO). Link: http://www.ncbi.nlm.nih.gov/pubmed/27599246

In 2016, NASA Applied Sciences concluded the five-year NASA Air Quality Applied Sciences Team (AQAST, *http://aqast.org)* and launched the new NASA Health and Air Quality Applied Sciences Team (HAQAST, *http://haqast.org*). Both teams focus on exploiting Earth science data and tools to serve the rapidly evolving information needs for air quality and public health, with HAQAST having a greater emphasis on health outcomes. HAQAST plans to build on the lessons and successes of AQAST, with team members conducting individual applied research projects in collaboration with air quality and health managers, as well as participating in yearly competed Tiger Teams for rapid-response applications. To this end, in June the program selected 13 investigators out of 58 proposals in response to the ROSES 2015 HAQAST solicitation. These selections represent a total investment of $5.1M over three years. The team is led by Dr. Tracey Holloway, at the University of Wisconsin--Madison.

Both AQAST and HAQAST host meetings every six months to review progress and meet with key stakeholders. Action items are identified at these meetings on the basis of the needs expressed by participating partners.

AQAST concluded with the 10th AQAST meeting in January 2016 (at the EPA in Research Triangle Park, N.C.). HAQAST kicked off with the first HAQAST meeting in November 2016 (at Emory University, adjacent to the CDC, in Atlanta). The AQAST meetings had become major events in the air quality management and applications communities, typically drawing more than 100 participants, with the final meeting scoring record attendance. The first HAQAST meeting continued this tradition and was held shortly after the formation of the team, with one day focused on team planning and collaboration, and one day focused on hearing from participating stakeholders including CDC, EPA, and others in the health and air quality communities.

HAQAST is benefiting from instruments of communication developed under AQAST including regular newsletters (to a mailing list of over 500 subscribers), Twitter (where the @NASA_AQAST handle has been changed to @NASA _HAQAST, with over 3,000 subscribers -- up ~30 percent in the past year), and focus on media outreach and public engagement of applied research. Websites and public communication efforts promote new team applied research, connects the team with stakeholder organizations, and offers a mechanism to

communicate NASA science related to air quality and health to the public and professionals.

Major AQAST/HAQAST highlights during 2016 included:

- Submission of the cumulative report, "The NASA Air Quality Applied Sciences Team (AQAST): A Retrospective," available on http://aqast.org. The report is a critical look-back at AQAST that gives a detailed history of the project, the reason it was formed, its activities, and the breadth of its impact. Of special interest is a detailed section entitled "AQAST Outcome Metrics," that includes publications (~140 at final count), number of air quality agency partners (33) participation at AQAST meetings, AQAST's social media presence, articles placed in more popular, non-academic outlets, the digital products members produced, and outreach activities. The report also muses on AQAST's successes as well as lessons that can be applied to future NASA efforts such as HAQAST.

- In April 2016, the Discovery Channel produced a 60 second video wherein President Obama used OMI NO_2 to discuss trends in air quality over the U.S. versus other countries (http://tinyurl.com/ObamaNO2).

- An assessment of AQAST's impact on the air quality management community was published: "Increasing the Use of Earth Science Data and Models in Air Quality Management" by Jana B. Milford and Daniel Knight in the *Journal of the Air & Waste Management Association*. The paper concludes: "Managers who have been involved with AQAST indicated that the program has helped build awareness of NASA Earth science products, and assisted their organizations with retrieval and interpretation of satellite data and with application of global chemistry and climate models. AQAST has also helped build a network between researchers and air quality managers with potential for further collaborations."

- Several new AQAST videos were released including:

    - Satellite Data and Energy Analysis: https://www.youtube.com/watch?v=vtqU_y70I5E

    - Satellite Data and Air Quality Management: https://www.youtube.com/watch?v=4VFm_00kGdE

    - Satellite Data and Models: https://www.youtube.com/watch?v=qFnQV6QPV6E

- HAQAST has launched a new website (http://haqast.org) and new mechanisms for team engagement online and with stakeholders, including frequent newsletters. The team is developing metrics for self-assessment,

which will be finalized at the second HAQAST Meeting in Seattle in February 2017.

IV. Assessment

The most common technical issue in the portfolio in 2016 remained the final transfer of projects to sustainable operations. Many projects have performed admirably in this task, while others still faced hurdles in completing this final step. The most common hurdle appeared to be more related to partner budget issues rather than partner capacity. Overall the portfolio exceeded expectations on technical performance.

The portfolio continued to carry a relatively high burden of uncosted funds in 2016. Associates worked diligently with principal investigators to uncover issues at their particular institutions. Many times this appeared to be an issue of "invoice lag" between NASA and the institutions, with costed funds not showing on NASA accounts until long after invoices had been submitted by grantees. However, significant progress was made.

Overall, the portfolio had a good track record for remaining on schedule in 2016, with limited no-cost extensions approved based on new opportunities or partner issues.

In general, the portfolio accomplished significant results and accomplishments in all areas in 2016, with a bright outlook for 2017.

V. Project Portfolio

At the end of 2016, the Health & Air Quality portfolio included 12 projects along with the activities of the 13-member Health and Air Quality Applied Sciences Team. The portfolio met or exceeded expectations on technical performance. By the end of the year, zero projects had an Application Readiness Level (ARL) of 1-3; ten projects were ARL 4-6; and two projects had achieved an ARL of 7-8. Seventy-five percent of projects increased by at least 1 ARL since the end of 2015, and 42 percent of projects increased by 2 ARLs. The appendix of this report includes project highlights for 2016.

VI. Program Management

The program conducted its 2016 Annual Team Meeting in September in Asheville, N.C. Approximately 35 attendees participated. Highlights included a partner address from the CDC Environmental Public Health Tracking Network and a state perspective address from the North Carolina Department of Environment and Natural Resources. Each project in the portfolio presented

their milestones achieved over the past year, plans for the coming year, ARL estimates, budgets, and any risks/opportunities foreseen. This included presentations from the satellite application awards (Aura, S-NPP). Additionally, there were presentations from ARSET and DEVELOP in capacity building, an introduction to HAQAST presented by Team Lead, Tracey Holloway (U. of WI), and an introduction to the NASA Space Apps Challenge presented by Shobhana Gupta. Presentations from the 2016 review can be found at the following link: https://weather.msfc.nasa.gov/conference/phconference_av_home.html.

Associates and Headquarters program management continued to meet regularly through 2016 to coordinate on costing issues, progress on project metrics, conference and workshop presentations, and on project results highlighted through web features or other internal and external venues. These discussions were briefed bi-monthly to Applied Sciences leadership at regularly scheduled program reviews.

Associates for Health & Air Quality continue to be Sue Estes (University of Alabama in Huntsville) and Ali Omar (NASA Langley Research Center). Additionally, the program extended the term of Shobhana Gupta, our American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellow.

VII. Community Leadership

The applications area presented and led sessions at meetings of the American Thoracic Society, the Air & Waste Management Association, and the American Meteorological Society (AMS). Sessions at the AMS annual meeting in New Orleans were held as part of the Seventh Conference on Environment and Health, of which NASA is a standing committee member. The conference's theme was, "Earth System Science in Service to Society." The 2016 meeting explored the growing connections between Earth science research results and the operational and applications community. NASA co-chaired the conference, and several investigators from the Health & Air Quality Applications area presented papers in a session titled: "NASA Earth Observations and Climate Change." Additional talks were given at the NASA Hyperwall at the booth in the exhibit hall.

The American Thoracic Society's annual meeting was held in May 2016 in San Francisco. NASA organized and chaired a session entitled "NASA's Satellites and Models for the Study of the Environment and Diseases." The session included presentations from NASA, the University of Alabama in Huntsville, and Colorado State University. The session was well attended and had high visibility due to recent wildfires in the western United States.

At the 2016 Air and Waste Management Association Annual Meeting in New Orleans, the program convened a panel to discuss and present NASA's satellite and sub-orbital measurements and models to address air quality and health applications. John Haynes presented an overview of the program portfolio, followed by presentations by PI Luca Delle Monache and associate Program Manager Ali H. Omar. The panel was chaired by Sue Estes and Shobhana Gupta. The NASA exhibit booth/Hyperwall display showcased NASA satellite observations and modelling animations, and Hyperwall talks by several NASA scientists and partners drew large crowds. NASA speakers presented additional application results and research during the platform sessions. NASA has agreed to continue its participation at the 2017 Annual Meeting in Pittsburgh, Pa.

John Haynes provided the Federal keynote address at the CDC's 2016 Summit on Environmental Hazards and Health Effects in Atlanta in January. The address focused on the continuing crucial partnership with the CDC across a variety of platforms including the Environmental Public Health Tracking Network. This partnership was first formalized in 2004 through an MOU which has since been renewed on multiple occasions.

The program presented in multiple sessions of the National Water Quality Monitoring Conference in Tampa, Fla., in May. Additionally, program representatives were able to take advantage of the location for a site visit to Mote Marine Laboratory in Sarasota, Fla., a critical partner in harmful algal bloom applications.

The American Public Health Association's annual meeting was held October 29-November 2, in Denver. The program presented a series of Hyperwall talks during the meeting at the NASA booth in the exhibit hall. These talks were well attended, and NASA won the blue ribbon as best exhibit at the conference.

The American Society of Tropical Medicine and Hygiene's annual meeting was held in Atlanta in November 2016. NASA's session focused on predicting and characterizing outbreaks of infectious and vector-borne diseases through the use of satellite remote sensing and model predictive capabilities. More than 250 people attended the session.

An Air Quality and Health Showcase was organized at NASA Goddard Space Flight Center in November. The showcase's aim was to introduce NASA remote sensing products and applications to new users and potential stakeholders. The program was pleased to have international participation at the event, including representatives of the World Bank and the UN.

The American Geophysical Union's Fall Conference was held in San Francisco in December 2016. The meeting offered multiple general sessions, each covering a different and exciting topic applicable across all fields of Earth and space science. Multiple portfolio investigators presented papers, posters, and

additional talks at the NASA Hyperwall. AQAST and HAQAST investigators also presented in multiple oral and poster sessions.

Many public outreach activities spanned the AQAST and HAQAST community, with HAQAST Team Lead Tracey Holloway named a AAAS Leshner Leadership Fellow to promote public engagement with science. Holloway was covered in an end-of-the-year article by NBC News reflecting on the potential for GOES-16 to benefit health and air quality in 2017. AQAST and HAQAST participated in a wide range of targeted meetings and ongoing stakeholder engagement. For example, Dr. Arlene Fiore delivered talks at the New York State Department of Environmental Conservation, the ExxonMobil Research and Engineering NOx Controls Workshop, and the Electric Power Research Institute ENV-VISION Conference. Dr. Tracey Holloway met with city, county, and local managers in Maricopa County, AZ, to discuss the potential of satellite data to support analysis of ozone precursors through OMI NO_2 and OMI HCHO retrievals.

The program continued its active participation in the USGCRP Climate Change and Human Health Working Group (CCHHG) in 2016. NASA researchers and members of the Health and Air Quality program leadership contributed to the USGCRP publication, *The Impacts of Climate Change on Human Health in the United States*. The report, released in April 2016, strengthens our understanding how a changing climate already affects human health and the threats it poses in the future. Examples of risks to human health include greater incidences and/or severity of temperature-related illnesses and deaths, vector-borne illnesses, and adverse effects of poor air quality. Additionally, the report identifies individuals and communities who are particularly vulnerable to these risks, including those with preexisting or chronic medical conditions, those with low income, children and pregnant women, and older adults. The full report can be found at the following link: https://health2016.globalchange.gov.

The program organized the first “NASA Tropospheric Emissions: Monitoring of Pollution (TEMPO) Applications Workshop” which took place in Huntsville, AL, in July 2016. The TEMPO mission is a geostationary observing platform that is expected to measure stratospheric and tropospheric ozone (O_3), nitrogen dioxide (NO_2), and other trace pollutants (e.g. formaldehyde (H_2CO)). The TEMPO Applications Workshop described planned mission products and engaged user communities to explore scientific applications in health and air quality planning and assessment, disaster response, emissions, exposure, and ecological impacts. More than 160 members of the applications community attended the workshop. TEMPO is slated to launch no later than 2021.

VIII. International Activities

The GEO Health and Environment Community of Practice (CoP) was re-invigorated under the leadership of Program Manager, John Haynes. The CoP hosted membership-wide telecons to discuss key topics at the nexus of Earth observations and health, including the addition of a Community Activity to the 2017-2019 GEO Work Programme, "Earth Observations for Health," which has three focus areas: 1) weather and climate extremes; 2) water-related illnesses; and 3) vector-borne disease. The NASA Applied Sciences Program issued a solicitation to support this Work Programme through ROSES 2016. This solicitation included a section targeting the "Earth Observations for Health" activity. The CoP plans to conduct an in-person meeting in 2017.

Associate Program Manager, Ali Omar presented a side event at the U.S. Center at the Conference of Partners 22 (COP 22) in Marrakech, Morocco, in November, titled, "Using NASA's Satellite and Airborne Measurements for Health and Air Quality Applications". In this event, attended by diplomats from several countries, he presented NASA's remotely sensed atmospheric measurements that have applications of societal benefit with a focus on the African continent. Smoke from African biomass burning regions along with the dust generated by the Sahara desert have deleterious impact on the regional air quality. The presentation showed the extent and long term trends of dust and biomass burning smoke from satellite measurements and airborne campaigns. NASA observations of fire and trace gas concentrations using satellite remote sensing and geographic information systems are particularly useful for managing environmental hazards. This fire data has led to the development of a rapid response system widely used throughout the world for both natural resource management and for firefighting by providing near real-time information. NASA's long term measurements of trace gas concentrations indicate changes in air quality. To show the impact of regulations, the presentation revealed to the delegates changes in trace gas concentrations in major urban areas in the United States between 2005 and 2012. The presentation also showed examples of how satellite measurements can be used in decision support and air quality regulation and monitoring policy.

At the December 2016 meeting of the AGU, HAQAST Team Lead Tracey Holloway chairing a U.S.-Korea joint discussion on applications of environmental satellite data for air quality and health. The meeting had over 30 participants, including science leads for the planned Korean GEMS satellite launch.

The program partnered with the Capacity Building program when former President Jimmy Carter contacted Administrator Bolden in spring 2015 requesting NASA's help in locating Yanomami villages in the Amazon to support The Carter Center's onchocerciasis ("river blindness") eradication efforts. A DEVELOP summer 2015 project found evidence of more than 160 potential villages in the study region by using a combination of NASA Earth observations and commercial imagery. Results and methods were delivered to The Carter

Center in August 2015. The success of this project led to its extension through the DEVELOP Spring 2016 term, resulting in the delivery of additional results in April. The Carter Center will use these tools in its work to eradicate river blindness in the Americas.

IX. Looking Ahead

During 2017 and beyond, the program will continue to expand its relationship with current and future relevant NASA missions, as well as field and Earth Venture (EV) campaigns. The program looks forward to the first full year of research from the HAQAST team, including the development of short-term Tiger Team initiatives. Two HAQAST team meetings are planned in 2017. The first meeting will be at the University of Washington in Seattle in February in cooperation with the US Forest Service. The second meeting will be in at Columbia University in New York City in November.

The program looks forward to the competitive selection of proposals from the ROSES 2016 GEO Work Programme solicitation, as well as the issuance of a new solicitation for Health and Air Quality Applications through ROSES 2017.

Sessions in 2017 are planned for the AMS Annual Meeting, the Air & Waste Management Association, and the American Public Health Association. In addition to a NASA session, the program plans to co-sponsor an applications workshop with the EPA and NIH at the American Thoracic Society annual meeting. The program also plans to participate in the Third Meeting of the Global Platform on Air Quality and Health in Madrid, Spain, sponsored by the World Health Organization in March.

The program will continue to keep abreast of studies and opportunities related to the *PACE*, ASCENDS, OCO-2, *HyspIRI*, and GEO-CAPE decadal survey missions. Additionally, the program is active in applications planning for the upcoming TEMPO Earth Venture mission, the MAIA Earth Venture mission, and the *geoCARB* Earth Venture mission.

The program will continue to examine “grand challenges” to the community. For example, accurate ground-level aerosol and constituent measurements from remotely-sensed columnar values represent another grand community challenge. While progress has been made in this area thanks to investments in algorithm development and targeted field campaigns, large discrepancies still remain. Ozone is a critical issue in this regard; aerosols over land areas with high albedo also have large errors. Even developed countries, such as the United States, have relatively sparse ground-level aerosol networks with remotely-sensed observations providing critical data to fill coverage gaps. Developing countries have even fewer ground sensors, and sometimes none at all. Satellite observations for air quality will be increasingly vital in the coming years.

The Health and Air Quality Applications program has established strong relationships with federal, state, local, and international partners to identify unique applications of NASA satellite observations and realize their operational use. These applications provide critical components for integration with various forecasts, models, and decision support systems. This will continue to be the case with the launch of upcoming NASA satellite missions. NASA's participation in health and air quality applications research and related transition to operations activities currently performed with EPA, NOAA, CDC, and others fills a significant niche in national capabilities and is a vital component of both current and future domestic and international programs and plans.

X. Appendix

Active Health & Air Quality Project Highlights (as of December 2016)

Project: Enhancing Data-driven Decision Support for Highly Invasive Vectors,

PI: Christopher Barker

Organization: University of California, Davis

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, was developed for the creation of distribution and suitability maps for invasive mosquitoes, *Aedes albopictus* and *Aedes aegypti*. These mapping systems will use near-real-time mosquito surveillance data, as well as NASA and non-NASA earth observations. These maps will be used to drive generalizable stochastic models for mosquito dynamics and spread on real landscapes to guide surveillance and control. This mapping system will be used to link models to real-time surveillance data through integration and evaluation in the CalSurv Gateway decision support system. The package models are expected to be adopted in other locations in the U.S. and southern Europe. A supplement was added in 2016 to this proposal to include Zika as well as dengue and chikungunya transmission models to predict human disease risk.

Project: Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems

PI: Arastoo Pour Biazar

Organization: University of Alabama in Huntsville (UAH)

- The main objective of this project is to improve the representation of physical atmosphere in air quality management Decision Support Tools (DSTs) used

in the State Implementation Plan (SIP) process for development and evaluation of emission controls under the provisions of the Clean Air Act. SIPs are at the nexus of health effects and economics. Nationally, the economic costs of such decisions can amount to billions of dollars. Thus, accuracy in the DST is critical to determining efficient cost effective strategies for attaining National Ambient Air Quality Standards (NAAQS). The target DST in this project is the Weather Research and Forecasting (WRF) and Community Multiscale Air Quality (CMAQ) modeling systems. CMAQ is an EPA-developed photochemical modeling system typical of the modeling systems now used by many states. This project will provide a system for routine utilization of NASA science and satellite products in the DST. The satellite products include surface skin temperature, insolation, and albedo from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor onboard polar orbiting satellites and Geostationary Operational Environmental Satellite (GOES) observations under NASA legacy science to complement polar orbiting observations. UAH also will be producing Photosynthetically Active Radiation (PAR) as a new satellite product to be used in the DST. The applied partners in this project are EPA's Atmospheric Modeling Division at the National Environmental Research Laboratory, the California Air Resources Board, Bay Area Air Quality Management District, Texas Commission on Environmental Quality (TCEQ), and Georgia Environmental Protection Division.

In 2016, the project demonstrated the impact of the proposed techniques to the partners at TCEQ using Texas as a test-bed for in improving air quality simulations. The results from these activities were presented at international scientific conferences and several papers are in preparation. In the following a short summary of these activities is presented. Satellite observations were used to improve biogenic emissions estimates and the new advances in biogenic emissions modeling to improve biogenic emission estimates used in air quality modeling activities. Due to high priority of this research for the state of Texas in their SIP modeling activities, Texas Air Quality Research Program provided complementary funding ($200K).

The approach to generate satellite-based PAR was to devise a parametric formulation to convert satellite-derived insolation into PAR. Thus, the first step in this process was to ensure that the insolation product used in the conversion was of highest quality. Two periods, summers of 2006 and 2013, were identified for evaluation. Also in 2016, the evaluation and use of skin temperature as a model evaluation metric was provided for the period 1-30 September 2013 which was part of the Houston campaign of Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) project. Aircraft measurements of skin temperature and air temperature were also used in this evaluation. The National Oceanic and Atmospheric Administration (NOAA) Comprehensive Large Array Data Stewardship System (CLASS,

www.class.ncdc.noaa.gov) was the source of the first skin temperature data tested. This data was derived from the Geostationary Operational Environmental Satellite (GOES) and is under the CLASS category of GOES Surface and Insolation Products (GSIP). The evaluation of NOAA-GSIP skin temperature product revealed unphysical air temperatures over the western U.S. including parts of Texas when compared to the Moderate Resolution Imaging Spectroradiometer (MODIS) observation.

Project: A Multi-Sensor Remote Sensing Approach to Predict Cholera

PI: Antarpreet Jutla

Organization: West Virginia University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is developing a satellite derived cholera prediction system, linking macro- and micro-environmental processes, for better decision-making strategies to prevent or minimize the impact of an outbreak. This team is identifying and synthesizing the role of acro-environmental processes for epidemic, mixed-mode endemic, and endemic cholera; developing a satellite data driven hydroclimatological risk model from conditions favorable for the three types of cholera; and developing a population based cholera outbreak index. This project will enhance the decision making of several health organizations; provide tools to justify development of appropriate water and sanitation infrastructure in the susceptible regions; and aid in understanding the impacts of climate change on the occurrence of outbreaks. This project hopes to inform the development of suitable long-term climate change adaptation policies regarding cholera.

  This project was awarded a socioeconomic benefits study augmentation in 2016.

Project: Evaluate, Enhance, and Apply Aura Products in Public Health Tracking

PI: Yang Liu

Organization: Emory University

- This interdisciplinary team brings together experienced remote sensing experts, environmental exposure modelers, and epidemiologists. By integrating ground observations and atmospheric chemical transport model simulations, the team is enhancing the existing OMI surface UV (OMUVB) product by better accounting for the impact of absorbing aerosols in the retrieval of surface UVB irradiance and erythemal doses. In addition, OMUVB

uncertainties due to SO2 and NO_2 absorption will be analyzed and corrected primarily in polluted urban regions. The conversion from the dose rate estimated at OMI overpass time to that at the local noon time and eventually to the daily-average dose will also account for diurnal change of aerosols. After evaluating the accuracy of the enhanced OMUVB product with ground measurements, the project will spatially match OMUVB exposure doses to 3,100 U.S. counties to study the association with county-level melanoma incidences reported by the National Cancer Institute. Major confounding factors such as indoor tanning use, education, poverty, health insurance, and rural-urban status will also be processed and included in the epidemiological model. The project team is working closely with the CDC Tracking Branch to develop UV exposure indicators and measures as well as detailed documentation for public release on the Tracking Network.

Project: Chemical Data Assimilation and Analog-Based Uncertainty Quantification to Improve Decision-Making in Public Health and Air Quality

PI: Luca Della Monache

Organization: University Corporation for Atmospheric Research

- One of the key tools used by decision makers across the U.S. to protect the public from adverse health effects caused by poor air quality is the National Oceanic and Atmospheric Administration (NOAA)/National Centers for Environmental Prediction (NCEP) operational air quality forecasting system; the National Air Quality Forecasting Capability (NAQFC). To enhance this decision-making activity this project aims to improve the accuracy of NOAA/NCEP short-term predictions of ground-level ozone and particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and to provide reliable quantification of their uncertainty, by exploiting NASA Earth Science Data with chemical data assimilation and analog-based approaches. In 2016, the project achieved the major milestone of running the 2D gridded deterministic procedure operationally on NOAA/NCEP computing platforms. The main components of the procedure include:

    - Automatic quality control of observations to eliminate spurious measurement values
    - Analog-based method applied to observation locations: for now only simple analog ensemble mean corrected with a Kalman filter bias correction
    - Spreading technique to generate gridded maps from the estimates at the observation locations

    This is a major step towards the transition to operations of the $PM_{2.5}$ deterministic predictions.

This project was awarded a socioeconomic benefits study augmentation in 2016.

Project: An Early Warning System for Vector-borne Disease Risk in the Amazon

PI: William Pan

Organization: Duke University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is a follow-on grant after successful completion of a Feasibility Study funded through the NASA Applied Sciences Health and Air Quality Program (2011-2013). Members of the proposal team developed a pilot malaria Early Warning System (EWS) for the northern Peruvian Amazon. Results of this study showed that meaningful malaria risk prediction can be achieved using statistical methods informed by an advanced NASA Land Data Assimilation System (LDAS), satellite-derived land cover, and human population and malaria surveillance data. Building on this study, this project will: 1) operationalize the malaria EWS to a larger geographic area with more fine-scale estimates of risk; 2) expand and evaluate system performance of cross-border risk estimates and add additional vector-borne disease endpoints, focusing initially on leishmania; and, 3) evaluate integrated Agent Based Model estimates into predictions. Operational status will be achieved by leveraging existing partnerships with the Ministries of Health of Peru and Ecuador.

Project: Downwind of the Flames: Assessing and predicting wildfire smoke related morbidity using satellites, in-situ measurements and models

PI: Jeffery Pierce

Organization: Colorado State University, Fort Collins, Colo.

- Exposure to particulate matter (PM) in wildfire smoke plumes represents a growing and uncertain threat to public health in the western United States. The area burned by wildfires in this region has increased in recent decades and is expected to increase dramatically over the next century. Wildfires pose a challenge to air quality managers and public health officials because 1) the timing of wildfire events is difficult to predict, 2) there are inadequate tools linking smoke forecasts to population exposures, and 3) the health risks associated with population exposure to wildfire PM are poorly understood. This project addresses these issues and operational challenges through the following research objectives: 1. Estimate the respiratory and cardiovascular

health risks for specific demographic populations exposed to wildfire PM. 2. Evaluate and develop forecast tools that predict wildfire PM concentrations, population exposure and the potential increased morbidity from exposure to wildfire smoke. The work includes a set of retrospective studies using an array of NASA earth observations (MODIS, MISR, CALIPSO), surface in-situ monitors and high-resolution modeling (3-km WRF-Chem) to estimate past PM exposures during major wildfire events. The project compiles and analyzes health-care records in the affected and nearby regions to estimate the health risks associated with exposure. The forecasting component will employ two tools currently used in decision making regarding wildfire PM: the WRF-Chem model and the BlueSky model framework. Both forecasting tracks require knowledge of current fires from NASA satellite observations. Evaluation of these tools is accomplished by running the same retrospective case studies (as pseudo-forecasts) and evaluating them using satellite and in-situ observations. The partnering agencies include the Centers for Disease Control and Prevention, Colorado Department of Public Health and Environment, Washington State Department of Ecology, and the City of Fort Collins.

In 2016, the project completed WRF-Chem simulations for three retrospective fires and compared simulations to observations and conducted sensitivity simulations for special cases. The project has also completed comparisons to BlueSky framework for significant fires and analysis of hospital records for 2013 fires in Colorado. Below are some testimonials from users and partners:

Gordon Pierce and Patrick Reddy, Colorado Department of Public Health and Environment:
"There is a clear need for improved smoke forecast models, especially those that can predict $PM_{2.5}$ concentrations at sufficient spatial resolution (~5km) and with improved accuracy."

Rosemarie Russo, City of Fort Collins:
"The impacts of wildfires in our community have been dramatic and devastating. The data generated from this project, as well as the forecasting tool planned for development, will greatly enhance the City of Fort Collins ability to plan for and respond to wildfire emergencies."

Project: Aura Chemical Reanalysis in support Air Quality Applications

PI: R. Bradley Pierce

Organization: NOAA/NESDIS/STAR

- This project utilizes the Real-time Air Quality Modeling System (RAQMS) in conjunction with the Operational Gridpoint Statistical Interpolation (GSI) 3-

dimensional variational data assimilation (DA) system to conduct a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements. It ingests several observations from NASA satellites including OMI (Total Column O_3, Tropospheric NO_2 Column), MLS (Stratospheric and upper tropospheric O_3, H_2O, CO, HCL, and potentially HNO_3 and N_2O profiles), AIRS (Tropospheric CO, and potentially CH_4 and N_2O profiles), MODIS (Aerosol Optical Depth, Fire Detection), TES (Tropospheric O_3, CO, CH_4 and N_2O validation) and ACE (Stratospheric and upper tropospheric O_3, H_2O, CO, HNO_3, CH_4 and N_2O validation). The main objectives of the project are to provide the air quality community with a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements, conduct regional chemical data assimilation experiments to quantify the influences in changes in NOx emissions on US air quality during the Aura period, and collaborate with International, Federal, State and Local air quality management communities in the utilization of the Aura and A-Train measurements and reanalysis for air quality assessment activities.

In 2016, NOAA Air Resources Laboratory (ARL) used July 2011 RAQMS chemical and aerosol analyses for NAM/CMAQ re-analysis to support Maryland SIP modeling.

Project: Improved Forecasts of Respiratory Illness Hazard from Gulf of Mexico Red Tide

PI: Richard Stumpf

Organization: NOAA Ocean Service

- This project was awarded through the NASA ROSES 2013-HEALTH solicitation. NOAA has conducted an operational forecast of algal blooms in Florida for ten years, and four years in Texas. This capability was developed by the PI's office and transferred to NOAA's Center for Operational Oceanographic Products and Services. The associated public conditions report provides an assessment of potential respiratory impact at county levels. The result has been successful in helping state monitoring, but much less so in supporting the broader community. The problem is that this forecast is issued twice per week and covers full county regions, and current capabilities do not support higher forecast resolution. Because the blooms are patchy, the accuracy at individual beaches is extremely low. Mote Marine Lab has implemented a "Beach Conditions Reporting System" (BCRS) that provides immediate information on respiratory irritation at the beach, but does not provide forecasts. Improvements in the integration of field observations, satellite data, and meteorological models will provide the needed higher resolution of the risk of respiratory impact. The goal of this project is to forecast the resolution and frequency of risk to "every beach, every day,"

rather than every county, twice a week. The methods should be applicable across the Gulf of Mexico. Currently, monitoring uses individual satellite sensors independently. This project will combine the standard products from multiple sensors and will improve the initial conditions going into the forecasts (e.g. removing clouds, loss of data, glint, etc.) and increase the temporal resolution, combining same day *Terra*, *Aqua*, and VIIRS (and ultimately *Sentinel-3*). The BCRS will be significantly enhanced with establishment of a smartphone based capability to allow trained volunteers to rapidly identify the presence of dense *K. brevis* blooms. Effective deployment of this network will be based on locations identified from the integration of new satellite products and previous reports. The result of the combination will be a finer spatial scale than currently available with the weekly water sampling and satellite images. The second part is forecasting the presence of aerosols onshore. The integration of the forecasts with improved daily detection would lead to simple and routine rapid forecasts that would be distributed through NOAA's operational HAB forecast system, the BCRS, the National Weather Service Beach Hazards Statement, as well as county and state public health departments.

Project: Using Remote Sensing and Environmental Data to Quantify Social Vulnerabilities to Heat Stress and Strengthen Environmental Public Health Tracking and Heat Mitigation Effort

PI: Tabassum Insaf

Organization: New York State Department of Health

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is integrating remote sensing data into CDC Environmental Public Health Tracking (EPHT) and capacity building efforts for climate change resilience at both the state and local health department levels. This project is using NASA Earth observations to characterize risk related to excessive heat in two populous Eastern U.S. states (New York and Florida). A fine-scaled daily heat metrics will be developed using meteorological re-analysis and remote sensing data for the years 2005-2013. Heat metrics will consist of daily maximum and minimum air temperatures, daily maximum heat index, and a newly defined measure called Net Daily Heat Stress (NDHS). The NDHS is an integrated measure of heat stress (and relief) over periods of a day or longer. Data for these metrics will then be incorporated into and made accessible to Local Health Departments through the state EPHT portals. Air temperature metrics derived from meteorological reanalysis and health data (hospital admissions and emergency department visits) are being developed exposure-response functions of heat stress, respiratory, cardiovascular and renal outcomes as functions of excessive heat levels (as defined by four daily heat metrics) and socio-demographic variables at the census tract level. This

analysis will allow for development of social vulnerability maps at the census tract level and integrate this information into decision support systems currently used in New York and Florida for community health assessment.

Project: Evaluate and Enhance *Suomi-NPP* Products for Air Quality and Public Health Applications

PI: Jun Wang

Organization: University of Nebraska–Lincoln

- This project is designed to evaluate and enrich the utility of *Suomi National Polar-orbiting Partnership* (*S-NPP*) data for applied science research. This project evaluating improvements in the application of the VIIRS aerosol product for operational monitoring of $PM_{2.5}$ air quality in the Remote Sensing Information Gateway (RSIG) at EPA. This information will also be provided to the CDC Environmental Public Health Tracking Network.

Project: An Early Warning System for Human West Nile Virus (WNV) Disease

PI: Michael Wimberly

Organization: South Dakota State University

- This project, awarded through the NASA ROSES 2013-HEALTH solicitation, is working to improve WNV forecasting and risk mapping tools to advance the effectiveness of mosquito control by helping to target limited resources more efficiently. This project is developing an improved WNV risk map highlighting infections across the state of South Dakota. The project will produce weekly predictive maps of WNV risk during the main transmission season. To improve predictions the team will incorporate streams of environmental data from current NASA products (NLDAS) and missions (*SMAP*). These methods to improve predictions by integrating environmental monitoring data with entomological surveillance data may be used by other states/areas where outbreaks occur.

HAQAST Project Abstracts (awarded in July 2016)

Project: A Satellite-Based Global Health Air Quality Index (HAQI): Development and Assessment

PI: Bryan Duncan

Organization: NASA GSFC

We propose to develop and assess a global, satellite-based, multi-pollutant Health Air Quality Index (HAQI), which is the continuation and enhancement of the previous work of our team members. The HAQI will be based on surface (i.e., "nose-level") concentrations of particulate matter (< 2.5 microns; $PM_{2.5}$) and nitrogen dioxide (NO_2) inferred from satellite data from 2005 to 2015 at 10x10 km^2 spatial resolution, and simulated ozone from a global atmospheric model of chemistry and transport. Such a HAQI will better communicate the risks of exposure to multiple air pollutants than the current U.S. Air Quality Index. The proposed work will prototype a future HAQI with potentially daily resolutions. Improvements in the methods to infer surface concentrations from satellite data and upcoming satellite instruments, including those on geostationary platforms (e.g., NASA TEMPO), will likely move us closer to achieving this goal.

Proposed Team and Tasks: Duncan (NASA, PI) and the proposed team's collective decades of experience and diverse expertise in numerous health and air quality areas will allow them to 1) successfully develop and implement the HAQI that will provide free and publicly-available information on the health risks of air quality around the world, and 2) effectively respond to the urgent needs of the health and air quality communities as part of HAQAST. Duncan is an active member of AQAST, working with the air quality community to use atmospheric models and satellite data for their applications. Co-I Lamsal (NASA) is the lead developer of the operational NO2 data product at NASA and pioneered a method to infer surface NO2 concentrations from satellite data. He was part of the original research team, including Collaborators van Donkelaar and Martin (Dalhousie U.), who in 2012 developed the concept of a satellite-based, multi-pollutant index. Van Donkelaar and Martin will provide high-quality surface PM2.5 data that they have developed. We will assess the suitability of including surface ozone as simulated by the NASA GEOS-5 atmospheric model, consulting with Collaborator Ott (NASA), who works with Duncan on ozone modeling. Together, $PM_{2.5}$, NO_2, and ozone account for the majority of premature deaths and morbidity associated with air pollution. We will evaluate the satellite-based HAQI and component pollutants with those from U.S. surface monitors which include observations of all component pollutants. We will calculate and evaluate trends in the satellite-based HAQI and component pollutants around the world using available surface data.

Health Outcomes: Co-I Sapkota (U. of Maryland) has expertise in exposure assessment and air pollution epidemiology and will establish the HAQI's predictive capability of adverse health outcomes, relating the spatial distributions of the HAQI and its individual component pollutants to health indices, such as hospital admissions for asthma, in the Mid-Atlantic U.S., an area with a relatively dense network of surface air quality monitors and health statistics. He will explore the prospects of daily HAQI and its components, NO2 from Lamsal and $PM_{2.5}$ estimates from Collaborator Gupta (NASA) for 2005-2006.

Societal Benefit & End Users: The proposed team will work with the identified end users to optimize the proposed datasets for their specific applications. Duncan and Prados (UMBC, Collaborator) will work to identify new end users and promote the datasets, including through NASA ARSET trainings. The satellite-based, multi-pollutant HAQI will benefit society by providing information, for instance, 1) on the health risks of air pollution to the general public, 2) to health and air quality managers around the world, and 3) to epidemiologists.

Project: Source Attribution Using Satellite Products and Models to Inform Air Quality Planning and Health Accountability

PI: Arlene Fiore

Organization: Columbia University

Recent space-based and modeling capabilities, combined with over a decade of high-quality U.S. air pollution measurements and public health records, offer novel opportunities to quantify changing air pollution levels and associated health effects. There is a growing need for health impact tools that draw on models and satellite products to quantify and prioritize sources that contribute to adverse health impacts. We propose to combine satellite products, ground-based measurements and earth system models to:

• conduct a multi-pollutant health impact analysis for at least the past decade over New York State (NYS);
• attribute background versus U.S. anthropogenic sources that can be linked with health analyses on daily to inter-annual time scales;
• estimate uncertainties in satellite-based and modeling approaches to source attribution and to exposure mapping at multiple time and space scales.

Specifically, we will generate annual, seasonal and, where possible, daily exposure maps for ozone, fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) over NYS for at least the past decade by combining existing satellite products (including multi-sensor fusion products) with ground-based measurements. We will exploit high-resolution models, including existing NYS

Department of Environmental Conservation (NYSDEC) simulations for past and present state implementation plans, to evaluate the temporal and spatial scales for which reliable exposure estimates can be derived from current satellite products, and to demonstrate the potential for future advances with instruments aboard geostationary platforms (e.g., TEMPO). By applying statistical models (standard Poisson time series regression and case-crossover), we will estimate spatiotemporal associations between air pollution levels and hospital admissions and emergency room visits in NYS.

Our NYS analyses will inform the NYS Department of Health (NYSDOH) surveillance system (Environmental Health Tracking Program) and serve as a model for other regions. We will probe daily to seasonal variability in individual background sources (e.g., stratospheric, international transport from Canada, Mexico, and Asia, and wildfires) in two models (GEOS-Chem and GFDL AM3) used to estimate background pollutant levels and to provide boundary conditions for regional regulatory modeling in support of National Ambient Air Quality Standard and regional haze rule planning. For international pollutant transport, we will also draw on a broad set of model simulations coordinated by the Task Force on Hemispheric Transport of Air Pollution. Satellite products and in-situ observations will be analyzed alongside these models to identify constraints on anthropogenic versus background sources and to provide uncertainty estimates. Our proposed approach is a step towards identifying source-specific exposure patterns needed to quantify accompanying health impacts for use in decision-making.

PI Fiore brings over a decade of experience analyzing models and observations for source attribution on multiple space and time scales ranging from individual pollution episodes to decadal shifts in the balance of background versus anthropogenic pollutant sources, as well as pollutant interactions with weather and climate. Co-I Kinney brings 30 years of experience in air pollution epidemiology and exposure assessment, and over a decade of leading integrated assessments of the health consequences of climate change including through air pollution. As a member of NASA AQAST, Fiore expanded her prior experience conducting policy-relevant science and delivering information to the air quality policy community and established new relationships with U.S. state and regional air quality managers. As part of HAQAST, our team will also add a strong environmental health perspective, building upon and expanding existing relationships with science and policy staff at U.S. EPA and at NYSDOH.

Project: Satellite-Derived $PM_{2.5}$ Grids with Dispersion Model Downscaling: $PM_{2.5}$ Data to Support Community-Scale Air Quality Health Research and Policy Development

PI: Frank Freedman

Organization: San Jose State University

We propose deliverables aimed to support air quality management district decision-making related to $PM_{2.5}$ exposure reduction policies and health research at community scales (100s of meters to kilometers). The deliverables will be based on 10-km horizontal resolution MODIS satellite-derived daily $PM_{2.5}$ grids, currently available from 2003–2011 as daily time series at the CDC Wonder data repository, and dispersion modeling to downscale these grids to community scales. The South Coast Air Quality Management District (SCAQMD) and Bay Area Air Quality Management District (BAAQMD) will be end-user points of delivery. Deliverables will be provided through web accessible visualization platforms developed and housed at the NASA-MIRO-SJSU Center for Advanced Atmospheric Research and Education (CAARE) at San Jose State University.

Three deliverables are proposed. Deliverable 1; will provide daily satellite-derived 10-km $PM_{2.5}$ grids for California using an improved version of its generation algorithm that incorporates MODIS C6 “Deep Blue” AOD retrievals. Deliverable 2; will be a web-based visualization platform that allows end users to view these grids with other earth science reanalysis and WRF-CMAQ modeling fields. Deliverable 3; will be a web-based modeling and visualization platform that runs a dispersion model at fine scale and blends its results with the 10-km satellite-derived grids to downscale the $PM_{2.5}$ fields to community scale.

These deliverables will support SCAQMD and BAAQMD programs to reduce exposure to $PM_{2.5}$ and associated toxic fine particulate species at community scales, where highest impacts due proximity to major roadways and other industrial centers are found. These impacts are socioeconomically disproportionate since relatively less-wealthy minority populations tend to reside in such high impact areas, which lends importance to this work beyond that motivated by reducing general population exposure. End-use of the high resolution $PM_{2.5}$ fields in air district applications of the U.S. EPA Environmental Benefits Mapping and Analysis Program (BenMAP) to assess health and monetary costs of $PM_{2.5}$ at community scale is planned.

Deliverable 1; will provide the daily regional $PM_{2.5}$ patterns at 10-km resolution to capture the urban background of the South Coast and Bay Area air basins. By incorporating “Deep Blue” AOD retrievals to improve particulate distinction near the surface, and running the algorithm just for California, more accurate $PM_{2.5}$ grids should be produced. These grids will be updated quarterly, the latency period of EPA Air Quality System $PM_{2.5}$ surface measurements needed in the algorithm to regress on the satellite aerosol optical depth measurements. Deliverable 2; is intended to better familiarize the SCAQMD and BAAQMD with the satellite $PM_{2.5}$ grids, particularly focusing on evaluating the product’s accuracy and utility in supporting agency operations pertaining to $PM_{2.5}$. The platform will allow the satellite grids to be either overlaid or viewed alongside other earth-science gridded products, such as the NASA NDVI/EVI and WRF-

CMAQ $PM_{2.5}$ grid modeling fields. WRF-CMAQ simulations of past high $PM_{2.5}$ episodes will be carried out to compare with the satellite-derived fields. Deliverable 3; will require development of a more efficient version of the AERMOD dispersion model, which we call C-MOD. We will design C-MOD similar to already developed C-TOOLS dispersion models, for efficient use by health researchers and public planners studying community-scale air pollution impacts. Two methods are proposed to blend the CMOD dispersion model with satellite-derived fields and downscale the results to sub-10 km scale. Resulting fields from the two methods will be compared and evaluated.

Baseline NASA funding will support the core scientific parts of project. Funding and computational resources for developing the visualization and other front-end parts of the deliverables will be supplied by CAARE.

Project: Supporting Health Impact Assessment Tools Using Remote Sensing and Earth System Models

PI: Daven Henze

Organization: University of Colorado

Ambient exposure to $PM_{2.5}$ is one of the top global health concerns. Remote sensing and global modeling are key tools for assessing health impacts from ambient exposure to $PM_{2.5}$, and for quantifying the benefits of air pollution control strategies, as the distributions and sources of $PM_{2.5}$ cannot be sufficiently quantified by in-situ measurements alone in many parts of the world, especially developing regions where air quality is a burgeoning issue.

Objectives: This project will expand upon previous work providing remote-sensing and model-based estimates of exposure and health impact response coefficients to the Climate and Clean Air Coalition (CCAC) of the United Nations Environment Programme. This work stems from a CCAC initiative to develop and apply National Action Planning Toolkits, which allows member nations to rapidly estimate air quality and climate impacts of arrays of mitigation options as part of their decision-making process. Through AQAST, NASA data are currently used within the initial version of one such tool—the LEAP-IBC Toolkit.

For our core project, we will continue to strengthen the applicability and scope of LEAP-IBC through updates to the remote sensing observations and modeling framework used in the toolkit. We will implement new multi-satellite fusion constraints on surface-level $PM_{2.5}$ from CALIPSO, MISR, MODIS and SeaWiFS directly into LEAP-IBC for improved accuracy and km-scale evaluation of air pollution exposure. The adjoint of a NASA global atmospheric chemical model (GEOS-Chem) is used to estimate the response of population-weighted $PM_{2.5}$ concentrations to emissions from any species, sector or location, and will be

extended to serve all CCAC member nations and to provide high-resolution products for cities included in the CCAC Urban Health initiative. Delivery of these results directly into LEAP-IBC will help serve air quality management activities across a broad set of countries and regions engaged in CCAC activities.

Qualifications: To successfully accomplish our core objectives, we will draw from considerable expertise in scientific and technical use of remote sensing data and air quality modeling (Henze), domestic and international air quality management (Anenberg), and environmental health (Kinney). From experience on both the research and air quality management sides of multiple AQAST projects, we are also able to identify, lead, and contribute to Tiger Team activities with clearly scoped deliverables and outcomes across a broad range of topics other than those highlighted in our core proposal, such as air quality toxics, urban heat islands, and epidemiology.

Impact: This project is highly responsive to the HAQAST solicitation, as we propose to use both multi-sensor satellite products and NASA earth system modeling to contribute to active air quality management programs. This directly addresses technical aspects of national and international environmental health and air quality policy; air quality management approaches in numerous countries; evolving policy needs arising from interactions among air pollution, health, and climate change; and the national and international organizations that address these issues. Quantifiable societal impacts include an expanded base of national air quality management organizations using these tools, the improvements these tools make to their abilities to estimate air pollution exposure, and enhanced capabilities for estimating how this exposure responds to domestic and international mitigation efforts. This work builds directly from AQAST funded activities that laid the groundwork for these projects, matched by support provided by the CCAC. The results will facilitate broader adoption of satellite-based $PM_{2.5}$ exposure estimates within organizations such as the UN, U.S. Department of State, World Bank, and World Health Organization, and expand a sustained user-base among these organizations for NASA products and HAQAST.

Project: Climate, Weather, Pollen, and Health: Quantifying Current and Future Risks

PI: Jeremy Hess

Organization: University of Washington

Aeroallergens, principally pollen, impose a substantial disease burden. In the U.S., allergenic pollens are released in spring, summer, and fall. Pollen causes significant morbidity among sensitized individuals, and approximately one-third of the population is sensitized. Syndromes associated with pollen exposure include

allergic rhinitis and conjunctivitis, wheezing, and exacerbations of existing pulmonary disease. Higher pollen count days are associated with increased emergency department visits for asthma and increased sales of over-the-counter allergy medications. Morbidity primarily results in work and school absenteeism and lost productivity, but life-threatening reactions sometimes occur.

Numerous meteorological and climatic factors affect pollen production, release, and distribution. Knowledge of these factors can be used to limit adverse impacts, principally by reducing exposure. Temperature, precipitation, sunlight, and CO_2 concentrations affect aeroallergen production through their influence on plant growth, pollen production, and timing of pollen release. Ground-level pollen concentrations are also influenced by weather—winds affect dispersal and rains affect persistence in the air. Better understanding of these factors facilitates short-term prediction of pollen levels, which can be used to limit exposure.

Most research on weather, pollen, and health has been done at local scales, and there have been limited efforts to link remotely sensed environmental data with changing pollen phenology. There have been few projections of climate change impacts on pollen phenology—and thus health—in the U.S. Few research findings have been translated into products to facilitate surveillance or reduce health impacts, and very little work has gone into activities facilitating climate change preparedness. Research relating climate, weather, pollen, and health on a national scale is needed to fill these gaps. Similarly, projections of climate change impacts on pollen and health are needed to facilitate public health adaptation activities.

Our goals are to advance understanding of the climate and weather factors affecting the spatial and temporal distribution of aeroallergens, to forecast pollen conditions a season in advance, and to project pollen conditions 10-40 years in the future. Specifically in year one, we will quantify the spatial and temporal relationships among climate and weather variables, vegetation, and taxon-specific allergenic pollen concentrations; develop regression models describing the pollen season; and use the derived historical associations in a predictive model to make an upcoming seasonal forecast and to project future pollen conditions with climate change. In year two, we will analyze the health outcomes associated with taxon-specific pollen concentrations using Google Trends data, produce seasonal risk maps of allergy disease burdens over the contiguous U.S., and identify synoptic weather patterns that are associated with allergic reactions. In year three we will identify meteorological characteristics that occur on peak pollen days; use these relationships to project the frequency of peak pollen days in future climates; and project future health impacts using the relationships between climate, weather, pollen, and health from our work in years one and two.

This study will provide a more comprehensive understanding of the spatial and temporal links between environmental conditions and pollen production and will clarify impacts of climate change on allergic disease burden. We will develop

several applied products, including applications in environmental health tracking and disease surveillance, risk mapping, prevention messaging, and warnings to limit adverse health impacts. Our public health partners and the general population can use these products and tools to limit pollen exposure, thereby reducing associated health impacts and financial burdens associated with aeroallergens.

Project: Membership Application for HAQAST: Satellite Data for Health and Air Quality Applications Across Scales

PI: Tracey Holloway (Team Lead)

Organization: University of Wisconsin-Madison

The NASA Health and Air Quality Applied Sciences Team (HAQAST) has the potential to transform the role of satellite data and other NASA products in the health and air quality management communities. If selected to participate in HAQAST, Tracey Holloway and collaborators would bring to the team expertise in air quality, satellite data, and public health, especially as applied to policy needs and stakeholder engagement. Two challenges in particular relate to the expertise of our group:

1) Evaluation of satellite data products as air quality and health indicators; and,
2) Integration of satellite data into decision frameworks for air quality and health.

Our activities focus on the U.S., although most methods and data sources are transferable to a global context. As such, we are able to contribute to collaborative activities through the HAQAST Tiger Team process, supporting analyses on a global basis. We have identified six projects where our group's HAQAST research holds the potential to transform the utilization of satellite data in health and air quality applications: 1) Integration of satellite-derived formaldehyde to support the National Air Toxics Assessment; 2) Enabling the use of satellite data for routine air quality model evaluation; 3) Characterizing ozone production regime with satellite data, in support of policies, planning, and trend assessment; 4) Reconciling "top-down" constraints on NO_2 from the OMI instrument with "bottom-up" factors determining U.S. NOx emissions in urban areas; 5) Applying MODIS products to the Regional Haze Rule and fire assessment, including new MODIS data from the GOES-R satellite launching in October 2016; 6) Applying a new, global chemical reanalysis from co-I Pierce to health and air quality applications.

We focus our activities on high-impact, low-cost opportunities to leverage the value of satellite data, guided by input from our stakeholder partners. Our activities will connect with a wide network of policy and health professionals, with especially close input from co-investigators Kirk Baker and Rob Kaleel. Through

HAQAST, we will build on current relationships and cultivate new collaborations. Our group will work to ensure that many existing AQAST stakeholders are well integrated with the new HAQAST.

Dr. Holloway is also applying to serve as HAQAST Team Leader. Holloway has served as Deputy Leader of NASA AQAST, overseeing communication and outreach activities, and participating in broader team budget, planning, and evaluation activities. Holloway has the background, experience and vision to support the new HAQAST. If selected, she will work to advance the benefit of NASA data and tools to stakeholders, to the public, and to global health.

Project: Using Earth Observations to Support Regional and National Environmental Health Surveillance

PI: Yang Liu

Organization: Emory University

Numerous epidemiological studies links ambient air pollution to excess morbidity and mortality. Historically these studies relied on ground monitoring stations, such as the U.S. EPA regulatory monitoring network, to estimate population exposure. The geographic sparsity of the monitoring network introduces exposure misclassification into the concentration-response (C-R) modeling process that can result in underestimated health risks. Limited data coverage also poses challenges for air quality and public health management agencies who need to evaluate the impact of background pollution levels and exceptional pollution events such as wildfires on both urban and rural populations. Methods that use NASA Earth observations to estimate air quality and to protect public health have advanced rapidly during the past 15 years, and this has become an active area of research worldwide. Satellite data can effectively extend air quality monitoring systems into poorly represented suburban and rural regions, and population-based exposure estimates at the regional and national scale are valuable tools for public health surveillance. In addition, NASA Earth observations advance our understanding of pollution sources and transport in three dimensions, which are important factors for air quality modeling routinely conducted at state environmental protection departments and the EPA.

For the baseline HAQAST activities, we propose to translate research knowledge to our public health partners in two projects. First, building on our long-standing collaboration with CDC's Environmental Public Health Tracking Network, we will conduct a national scale epidemiological study to link age-specific county-level daily counts of emergency department (ED) visits with fused air pollution exposure estimates from satellite observations, model simulations and EPA ground measurements to demonstrate an important application of Tracking's environmental health surveillance data. The expected deliverables will be a set of

Tracking-style Environmental Public Health Indicators and Measures based on our results. The short-term societal benefits of our project will be to fulfill the Tracking Program's strategic goal of facilitating research and capacity building using Tracking data, and to enhance its capabilities to deliver spatially-resolved health risk information to its partners nationwide. In the long term, our work can potentially inspire similar studies, and attract more states to join the Tracking Network.

Second, partnering with the Colorado Department of Public Health and Environment (CDPHE), we will conduct a multi-year time series epidemiological study to evaluate the health impact of air pollution levels elevated by wildfires in Colorado. The objectives of this project are (1) to improve surface exposure estimates related to wildfire smoke using advanced data fusion approach, and (2) to determine whether increases in air pollution level due to wildfire smoke contribute to ED visits and acute hospitalizations for respiratory and cardiovascular outcomes during the fire season in Colorado. The expected deliverables include: (1) region-specific CR functions of various health endpoints during the fire season, (2) gridded estimates of health impacts due to wildfires in Colorado, and (3) gridded air pollution estimates in the western U.S. Our results will help CDPHE to better understand the atmospheric processes that lead to pollutant accumulation due to wildfire smoke, and refine its estimate of public health burdens of fire activities in Colorado. The short-term societal benefit of this project will be to help CDPHE refine its estimate of public health burdens of fire activities in Colorado. In the long term, our results will likely contribute to policy change in fire-prone states regarding public health actions before and during wildfires.

Project: Satellite-Based Products and Tools to Support Quantification and Attribution of Background Ozone

PI: Jessica Neu

Organization: Jet Propulsion Laboratory

Increases in background ozone are a major air quality concern, particularly for the Western United States, where background ozone may limit states' ability to meet the new federal ozone standard in some locations. We plan to develop a program for applying satellite measurements to the quantification and attribution of background ozone, with an emphasis on air quality in the Western United States. Recent publications from our group demonstrate our capability for combining satellite measurements with both global-scale and regional models to quantify background ozone and attribute it to long-range transport, stratosphere-troposphere exchange, and wildfire emissions. These publications were brought in to the debate over the EPA's new ozone standard, and a new EPA white paper on background ozone as well as regional activities such as the California

Baseline Ozone Transport Study show that background ozone is a major concern when it comes to meeting the new standard, particularly in the Western US.

This proposal specifies the qualifications and expertise in both satellite measurements and modeling that the PI and her team would bring to HAQAST and describes three activities targeting the long-range transport, stratospheric, and wildfire components of background ozone that will be developed under baseline funding, with a particular focus on products to be delivered to our air quality management partners at California Air Resources Board and the South Coast Air Quality Management District. It also describes our potential contribution to Tiger Teams.

The proposed work addresses the HAQAST topic areas of long-range transport and its implications for air quality management approaches, assessment of the information content of satellite observations, and support for regional modeling capabilities.

As a member of the HAQAST team, the PI proposes to:

1. Develop a set of satellite-based analyses aimed at supporting quantification and attribution of changes in background ozone in the Western U.S. We will provide critical information to policy makers by analyzing how background ozone has responded to changes in international emissions (particularly those from East Asia) as well as to natural variability in long-range transport and stratosphere/troposphere exchange over the past ~10 years.

2. Use assimilated satellite measurements to generate ozone lateral and upper boundary conditions for regional models. This work will improve the accuracy of these models and their estimates of the contribution of background ozone to high ozone days and thus support development of air quality management policies.

3. Exploit our group's unique capability to generate regional maps of tropospheric ozone profiles from a combination of AIRS and OMI to identify and quantify ozone associated with long-range transport, stratospheric intrusions, and wildfires to aid in exceptional event analysis.

Background ozone has both health implications and serious regulatory impacts, and our work will provide much-needed observational constraints on the magnitude and variability of background ozone to aid air quality management decisions.

Project: Facilitating the Integration and Adoption of Satellite Products for Decision Support During Wildland Fire Smoke Episodes

PI: Susan O'Neill

Organization: USDA Forest Service

We propose to create the customized products, tools, and training to foster adoption of satellite products into the decision making and public health advisory discussions that occur during wildland fire smoke episodes. Specifically we propose to work with the dedicated incident command smoke specialists—Air Resource Advisors—that are part of the Wildland Fire Air Quality Response Program to incorporate satellite information into their workflow. Air Resource Advisors work directly with local public health agencies and air quality agencies to craft public information and advisories. Incorporating satellite information into these products directly affects the public, as well as affecting decisions occurring within the fire's incident command. To accomplish this we propose a baseline activity composed of three components: (1) mine, analyze, synthesize, and deliver earth observations in tailored formats to Air Resource Advisors (ARAs) and public air quality and health agencies; (2) enhance the use of earth observations for smoke model evaluation and validation; and (3) enhance the use of earth observations within the smoke prediction modeling chain. We—the U.S. Forest Service (USFS) AirFire Research Team—are ideally positioned to achieve our objectives and project goals because we are an applied science team with a long history of extensive collaborative development of fire and smoke related tools in use by managers and regulators across the U.S. and internationally. We are also the primary science advisors to the interagency U.S. Wildland Fire Air Quality Response Program (WFAQRP) and work directly with WFAQRP Air Resource Advisors, technical specialists focused on smoke that serve as part of fire incident and regional command structures, to enable their communication with local public health agencies in creating public smoke advisories and guidance. Satellite information are currently available from a variety of sources; the goal is not to duplicate such efforts, but rather to mine and distill them to deliver the information important to periods of widespread wildfire smoke impacts in a manner easily understood and useful to technical specialists such as ARAs, air quality (AQ) agencies, public health agencies, and the public through customized and tailored products. Information created by this project will take advantage of the existing communication pathways and delivery systems in use by the operational fire and health communities (customized websites, blogs, infographics, sound bites, social media including Facebook and Twitter).

Project: HiRes-X: Scientific and Geographic Extension of an Operational High Resolution, Prognostic Air Quality System Providing Smoke Impacts Forecasts for Health Protection, Ecosystem Management and Economic Development Using Earth Observations

PI: Armistead Russell

Organization: Georgia Tech University

Wild land fires constitute the largest source of primary fine particulate matter ($PM_{2.5}$) in the U.S., in addition to being among the largest sources of secondary $PM_{2.5}$ and ozone precursors. Fire emissions are of specific concern from a health standpoint as a variety of studies suggest that biomass-burning generated PM is more toxic than other components. However, fires are important to ecosystem, forest and crop health, so land and forest managers are looking to increase prescribed burning both for economic and ecosystem benefits. Balancing these benefits with the potential impacts on air quality is being accomplished in Georgia using the HiRes air quality/burn impact forecasting system.

We propose to advance the operational HiRes system to HiRes-X, expanding its capabilities and use of Earth observations, and extending its domain to additional states in the Southeast. Burn forecasts would be used by local, state and federal health, forest, agriculture and air quality agencies in the region. More extensive use of Earth observations are planned, including high-resolution products from the Visible-Infrared Imaging Radiometer Suite (VIIRS) and NASA *Aqua* Atmospheric Infrared Sounder (AIRS) for improved detection of prescribed burns. A new tool will be added to the system to allow rapid updating of when and where actual fires occur. Comparisons between HiRes-X fields, satellite observations and ground-based measurements are expected to improve remote sensing-based emissions estimates. Additional objectives include using forecasts in CDC's public surveillance and epidemiologic analysis and the deployment of air quality sensors in burn-impacted regions to provide additional information for system improvement, public safety and educational purposes.

While the system is operational in Georgia where the benefits have been recognized, the expansion to additional states will further the health, economic and ecosystem benefits. During the conduct of this study, we plan to extend the fire forecasting to Alabama, Florida, and South Carolina, though further growth is possible. Health benefits will be derived from both an ability to warn areas where impacts will be most severe and a capacity to plan fires with minimal impacts on populated regions. Economic and environmental benefits will be realized through additional opportunities for burning, which would improve forest health. These benefits are particularly important in regions currently most impacted by fires as they are typically lower socioeconomic status areas and suffer from a lack of air quality monitoring such that they have little warning or knowledge of potential adverse air quality events. We will deploy multisensory air quality monitors at high schools in the region to enrich the current monitoring network. We will also provide educational opportunities to those high schools to learn about air quality, health and Earth observation systems. Public and stakeholder engagement is planned via workshops and our current roles in regional air quality studies that have regulatory impacts. As part of the research, we explicitly include the evaluation of how well the system advances and extension to additional regions are meeting the objectives and achieving the desired benefits.

The potential health, economic and ecosystem benefits and making use of the rapidly growing array of Earth observations, are directly aligned with NASA's objectives. Further, the system is designed to adapt to additional observational systems expected in future years. Our website is used by regional stakeholders, and will be updated to further educate people on the types and uses of Earth observations.

The team includes experts in the areas of air quality, health and forest management. Not only do they conduct fundamental and applied research and publish in leading technical journals, they work closely with local, state and federal agencies and regional stakeholders to identify and address specific needs.

Project: Novel Use of NASA Data with Emission Data Assimilation to Support U.S. National Air Quality Forecasting Capability and WMO Regional Chemical Reanalysis

PI: Daniel Tong

Organization: George Mason University

The World Health Organization estimated that exposures to air pollution in 2012 caused 7 million premature deaths worldwide, making it the single largest environmental risk today. Among all pollutants, fine particles ($PM_{2.5}$) are most closely associated with increased lung cancers and other cardiovascular diseases. In the United States, over one third of the population lives in areas not attaining the health-based National Ambient Air Quality Standards. To mitigate the widespread health risk, regional and national air quality forecasting systems, including the National Air Quality Forecast Capability (NAQFC), were established to enable the nation to foretell pollution levels with 48-hour lead time, so that health authorities can take actions to protect sensitive groups with early warnings and other mitigation measures.

A team of air quality forecasters, Earth scientists, and air quality managers has been assembled to substantially enhance the nation's pollution forecasting capability through:

1) Emission data assimilation: Assimilate NASA observations in the emission modeling processes to improve emission inputs. Use OMI NO2 to update anthropogenic emission inventories, OMI HCHO retrieval to constraint biogenic isoprene emissions, and MODIS and MISR aerosol data to improve dust and fire emissions.

2) Using NASA data in regional chemical analysis: Built upon the success of the previous AQAST Tiger Team project, Regional Chemical Reanalysis, our team

has completed a prototype using an Optimal Interpolation (OI) scheme to generate 12-km resolution hourly atmospheric chemical reanalysis over the Continental U.S. The AQAST project finishes appropriately by transitioning the prototype system to a production system through the replacement of the OI scheme with the NCEP operational Grid Statistical Interpolation 3DVar scheme.

3) Using NASA data in chemical data assimilation: Leverage the data assimilation framework developed from ongoing AQAST projects to assimilate a suite of satellite and ground data (MODIS AOD, VIIRS AOD, AIRNOW $PM_{2.5}$) to improve a) the initialization of NAQFC chemical fields, and b) deterministic prediction with detailed quantification of uncertainties using either Optimal Interpolation (OI) or Gridpoint Statistical Interpolation (GSI) method;
4) Evaluating NAQFC prediction: NAQFC outputs will be evaluated with NASA satellite, suborbital and ground observations (MODIS, DISCOVER-AQ, AERONET and CALIPSO).

The proposed work directly contributes to the HAQAST objectives by applying Earth Observations to improve a key decision-making tool: air quality forecasting (AQF). The new emission data assimilation capability improves AQF performance and enhances responsiveness of such a tool to air quality and public health managers. Although the proposed study focuses on improving the national AQF system, the NASA data assimilation capability can be applied to similar regional and international forecasting systems. AQF is critically relevant to air managers to produce air quality advisory. Therefore, improvement of AQF performance through utilizing Earth observations is an integral part of the HAQAST efforts to advance the health and air quality management communities' sustained use of NASA data in decision-making.

Project: Health and Air Quality Applied Sciences Team: Using Science to Inform Management

PI: Jason West

Organization: University of North Carolina

Over the past decade, the PI has established himself as a leader in using atmospheric science and modeling to drive health impact and quantitative policy analyses, connecting air pollution, climate change, and energy with human health and policy. He was the first to use a global atmospheric model for a health impact analysis, and his research group was the first to use a single global model and later an ensemble of global models to estimate the global burden of disease due to outdoor air pollution. His abilities to conduct interdisciplinary studies that address key policy questions are exemplified by studies of the costs and health benefits of methane mitigation as a tool for ozone air quality management, and of the co-benefits of global greenhouse gas mitigation for global air quality and health. As a member of HAQAST, the PI can also offer a strong understanding of atmospheric science, air pollution health effects, and climate change, leadership and communication of science for informing decision-making, and abilities to work in atmospheric modeling on global, regional, and local scales, human health impact assessment, economics and quantitative policy analysis, and energy-economic modeling.

Here we aim to make atmospheric science meaningful for government decision-making through two tasks. First, we will estimate global surface ozone concentrations through a statistical fusion of global surface observations and global multi-model ensembles. The combined global ozone dataset will be then provided to the Global Burden of Disease (GBD) team for their use in evaluating the global health burden of ambient ozone. Since previous GBD exercises estimated ozone concentrations using a single model and no observations, we expect our work to significantly improve forthcoming GBD estimates, leading to a more accurate understanding of ozone exposure and its health effects globally. We will use an unprecedented global database of ozone observations currently being compiled for the Tropospheric Ozone Assessment Report, and multiple global model simulations for the HTAP-2, ACCMIP, and AerChemMIP multi-model intercomparisons. Three methods of statistical data fusion will be used in succession based on their complexity, using observations to correct for model biases. This project uses NASA satellite products for model evaluation, directly by our study or by the modeling teams. The target audience will be the GBD team, and by strengthening the GBD assessment, we will reach governments and decision-makers globally.

Second, we will model the global air quality and health co-benefits of GHG reductions currently pledged under the 2015 Paris Agreement to address climate change. Our previous co-benefits research has revealed that for global GHG reductions, a significant fraction of the co-benefits realized in the US may result from foreign emissions controls. Here we will use simulations of a reference scenario and of the Paris Agreement

commitments, as modeled previously in the global energy-economics model GCAM, to give global air pollutant emissions. A global atmospheric model will simulate concentrations of ozone and $PM_{2.5}$ in 2030 (the current Paris target period), and in 2050 and 2100 for scenarios that continue Paris goals with the same level and increased levels of commitment. Global mortality impacts of reduced air pollution will be assessed using the PI's methods. We will further conduct simulations that separate co-benefits due to emissions from the U.S. vs. foreign nations. This project will use NASA meteorological re-analyses as input, and NASA satellite products to evaluate the simulation for the base year (2008-2012). This project will aim to inform decisions by the US EPA and other government agencies, as well as air quality and health managers worldwide.

Project: Spatiotemporal Variability of Ammonia through Syntheses of In-Situ-, Ground-Based, and Remote Sensing Measurements

PI: Mark Zondlo

Organization: Princeton University

The focus of this proposal is to identify how remote sensing measurements of ammonia (NH_3) can be used to help improve air quality forecasts of $PM_{2.5}$, a criteria pollutant that has proven difficult to reduce in urban regions. Gas phase NH_3 is well-recognized to be a critical aerosol precursor species and key component of nitrogen deposition in sensitive ecosystems, but unlike criteria pollutants NOx and SOx, NH_3 emissions are currently unregulated in the U.S. Part of the problem is the extreme difficulty of measuring gas phase NH_3. Recent advances in remote sensing measurements of NH_3 from IASI, CrIS, TES, and AIRS provide a great opportunity to improve NH_3 emission inventories and capture the high spatiotemporal emissions related to agriculture. However, they remain unvalidated and it is unclear how useful measurements are at small spatiotemporal scales needed for air quality research and forecasting. The proposed activities will validate IASI and CrIS at the single pixel scale and examine spatial and temporal variations of NH_3 by synthesizing in-situ and remote sensing data. In addition, case studies of nitrogen deposition and agricultural emissions will provide additional data to improve NH_3 modeling efforts. External collaborators on the air quality model sides will provide feedback on case studies to detect NH_3 plumes from agriculture. Field data will also be integrated into reactive nitrogen components of land and atmosphere Earth System models to assess relationship with other biogeochemical emissions and how climate change may alter future emissions.

Abbreviations and Acronyms:

AAAS: American Association for the Advancement of Science
AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
AGU: American Geophysical Union
AIRS: Atmospheric Infrared Sounder
AMS: American Meteorological Society
AOD: Aerosol Optical Depth
AQ: Air Quality
AQAST: Air Quality Applied Sciences Team
ARL: Application Readiness Level
ARSET: Applied Remote Sensing Training program
ASCENDS: Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
BCRS: Beach Conditions Reporting System
CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CCHHG: Climate Change and Human Health Working Group
CDC: Centers for Disease Control and Prevention
CMAQ: Community Multi-scale Air Quality
CMIP: Coupled Model Intercomparison Project
CoP: Community of Practice
CrIS: Cross-track Infrared Sounder
DISCOVER-AQ: Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DST: Decision Support Tool
EE: Exceptional Event
EOS: Earth Observing System
EPA: Environmental Protection Agency
EPHT: Environmental Public Health Tracking
ESD: Earth Science Division
EWS: Early Warning System
GCAM: Global Change Assessment Model
GEO: Group on Earth Observations
GEO-CAPE: GEOstationary Coastal and Air Pollution Events
GEOS-Chem: Goddard Earth Observing System–Chemistry
GFDL: Geophysical Fluid Dynamics Laboratory
GOES: Geostationary Operational Environmental Satellite
GSFC: Goddard Space Flight Center
GSIP: GOES Surface and Insolation Products
HAB: Harmful Algal Bloom
HAQI: Health Air Quality Index
HyspIRI: Hyperspectral Infrared Imager
IASI: Infrared Atmospheric Sounding Interferometer
LDAS: Land Data Assimilation System
MAIA: Multi-Angle Imager for Aerosols
MISR: Multi-angle Imaging Spectroradiometer

MODIS: Moderate Resolution Imaging Spectroradiometer
MOU: Memorandum of Understanding
MSFC: Marshall Space Flight Center
NAQFC: National Air Quality Forecast Capability
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NCEP: National Centers for Environmental Prediction
NDHS: Net Daily Heat Stress
NDVI: Normalized Difference Vegetation Index
NESDIS: National Environmental Satellite, Data, and Information Service
NEX: NASA Earth Exchange
NLDAS: North American Land Data Assimilation System
NOAA: National Oceanic and Atmospheric Administration
OCO-2: Orbiting Carbon Observatory-2
OMI: Ozone Monitoring Instrument
PACE: Plankton, Aerosol, Clouds, ocean Ecosystem
PAR: Photosynthetic Active Radiation
PI: Principal Investigator
PM: Particulate Matter
$PM_{2.5}$: Fine Particulate Matter
RAQMS: Real-time Air Quality Modeling System
ROSES: Research Opportunities in Space and Earth Sciences
S-NPP: Suomi National Polar-orbiting Partnership
SBA: Societal Benefit Area
SIP: State Implementation Plan
SMAP: Soil Moisture Active Passive
STAR: The Center for Satellite Applications and Research
TCEQ: Texas Commission on Environmental Quality
TEMPO: Tropospheric Emissions: Monitoring of Pollution
TES: Tropospheric Emission Spectrometer
TRMM: Tropical Rainfall Measuring Mission
UAH: University of Alabama in Huntsville
USGCRP: U.S. Global Change Research Program
USGEO: U.S. Group on Earth Observations
UVB: Ultraviolet B
VIIRS: Visible Infrared Imaging Radiometer Suite
WMO: World Meteorological Organization
WNV: West Nile Virus
WRF: Weather Research and Forecasting
WRF-AERMOD: Weather Research and Forecasting–American Meteorological Society/Environmental Protection Agency Regulatory Model
WRF-Chem: Weather Research and Forecasting–Chemistry

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